VLF Magneto-Inductive Signaling and Navigation

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LONG-TERM GOAL

The long-term goal is to establish the feasibility of using Very Low Frequency (VLF) Magnetic Induction (MI) as a practical technology for providing navigation information to divers or Autonomous Underwater Vehicles (AUVs) performing any of a variety of tasks in choppy salt water where RF and sonar methods are difficult to apply.

OBJECTIVES

In this program, we make use of magnetic fields as the source of navigation information. The earth's magnetic field has been used for millennia as a navigation aid. The field exists almost everywhere, it penetrates salt water and most rock formations and it has a specific direction that is useful for keeping objects oriented anywhere they are deployed.

The specific objective of this program is the development of an MI-based navigation system for use by divers, swimmers or by small AUVs in a wide range of countermine and reconnaissance missions, conducted primarily in the surf zone or very shallow water. The approach will be platform independent, immune to surf noise and geographic variations, be clandestine in operation and provide an operating radius of at least a kilometer.

APPROACH

Foster-Miller is teamed on this program with the Autonomous Underwater Systems Institute (AUSI) who are charged with assistance in the design of the tests to be conducted and in evaluating results and suggesting further direction of the development.

MI Systems Ltd. of Nova Scotia is tasked with the implementation of the hardware and firmware needed to implement the navigation system and to provide support in conceptual development and test and evaluation.

Foster-Miller is driving the overall development of the system and working on its integration into the vehicle and its potential missions.

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WORK COMPLETED

During 1998 Phase I of the program was completed, the Phase I Option was conducted, and work on Phase II began.

The Phase I effort was a feasibility analysis of MI technology as applied to navigation. Here the ‘shape’ of the field – its local directionality – is just as important as its amplitude, and consideration was given to the number, size and geometry of the source coils, and details of the magnetometer detector. A straw man concept for a system was developed and described in the Phase I report.

In the Option task, an operating source coil was placed under salt water, it was driven at 50 Hz and the field pattern was measured at short range.

In Phase II, newly underway, Foster-Miller is considering new systems approaches and planning a series of equipment designs and field tests at increasing operating ranges in increasingly challenging test environments.

RESULTS

As a result of our Phase I studies, it was initially concluded that the most likely first approach to the design of a navigation system would be to deploy two source coils a known baseline distance apart and each in a known compass alignment. The geometry (idealized) is shown schematically in Figure 1.

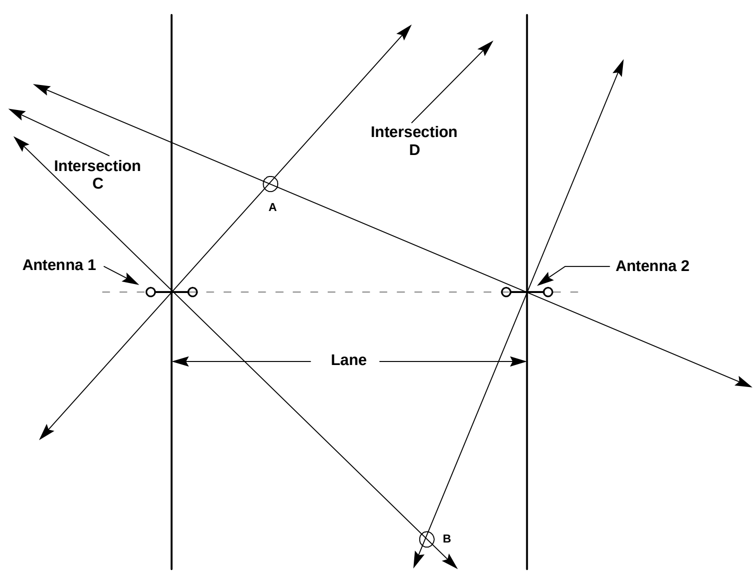

Figure 1. Two Source Coil Navigation Geometry

A receiver can easily find its angular (not radial) displacement with respect to a source coil and determine that it lies along one of two perpendicular lines passing through the source coil’s center. These are **lines** because radius cannot be determined, and there are **two** of them because symmetries in the magnetic field lead to 90^{o} ambiguities in angle.

During the Phase I Option, field shapes and angular displacements were measured at short range in 7-ft deep salt water. The results indicated excellent agreement between the calculated theoretical field pattern and measured angles, both in air and salt water as shown in Table 1.

Table 1

Comparison of Theoretical and Experimentally Measured Bearing Angles

		Bearing				
Coordinates		**Theoretical**	**Measured**		**σ**	**σ**
Y	**X**		**Water**	**Air**	**Water**	**Air**
10	5	130.60	126	135	21.14	19.38
5	5	161.56	140	158	464.99	12.70
0.001	5	90.03	90	90	0.00	0.00
-5	5	18.43	14	13	19.62	29.48
-10	5	40.60	36	51	21.14	108.21
					4.59	2.61
10	10	161.56	156	159	30.95	6.57
5	10	198.44	203	196	20.83	5.94
0.001	10	90.01	92	88	3.96	4.04
-5	10	-18.43	-23	-18	20.88	0.18
-10	10	18.43	20	20	2.46	2.46
					1.78	0.88
-5	10	-18.43	-17		2.04	
-5	5	18.43	18		0.18	
-5	0.001	90.00	87	91	9.00	1.00
-5	-5	161.56	162	166	0.19	19.68
-5	-10	198.44	205	205	43.08	43.08
					1.48	2.66
-10	10	18.43	17		2.04	
-10	5	49.40	43		40.96	
-10	0.001	90.00	90	92	0.00	4.00
-10	-5	130.60	128	130	6.75	0.36
-10	-10	161.56	159	164	6.57	5.94
					1.50	1.07

A transmitter coil was fixed on the sea bottom with its axis in a North – South alignment. The coordinates in the table are in meters measured N – S (y) and E – W (x) from the center of the coil.

The column of theoretical bearings in the table was calculated from theory and compared with measurement both in air and under water. This comparison was quantified using a figure of merit called σ, defined as follows

$$\sigma = \frac{\sqrt{\sum_{i}\left(\theta_{i,\,meas} - \theta_{i,\,theor}\right)^{2}}}{N}$$

i.e., as the root of the sums of the squares of the differences between theory and experiment, normalized by the number of measurements. This σ is therefore a measure of the overall deviation of a measurement set in absolute angle (not as a percent of angle).

As can be seen in the table, the angular errors all fall within a 1 to 2.5 degree range except for the point at (+5, +5) which has a 21.5 degree error in water. Inspection of the original dataset shows that the individual measurements of the x and y components of the field lead to a bearing at minimum signal of 156.5 degrees, quite consistent with the other measurement accuracies in Table 1. It appears that we are justified in ascribing the error at (5,5) to human (recording) mistakes.

During the opening tasks of Phase II, a new mathematical approach to the field navigation equations is being studied. This new approach permits us to obtain unambiguous fixes anywhere within range of a **single** source coil and with reduction of positional error directly proportional to the number of fixes obtained per unit path distance. The ambiguities are removed by context and the error is reduced by the averaging inherent in increasing the number of readings taken. The prospects for system simplification are exciting!

IMPACT/APPLICATION

The development of a reliable and accurate means of navigation for use by small AUVs in very shallow water or the surf zone is of pivotal importance to the use of these vehicles in all of the missions for which they have been proposed. Two such missions would include general reconnaissance, where Side Scan or Synthetic Aperture Sonar equipped AUVs might be used to scout the underwater hydrography, or a more detailed search, in which the AUVs might be used to gain an assessment of the actual number and location of undersea mines. In both scenarios it is obvious that accurate positional information is needed both to make the data gathered useful to the user and to allow the registration of data sets collected by multiple vehicles.

There are few ways to accomplish the needed localization. Conductive seawater eliminates the use of any RF technique entirely. What remains is sonar and the low frequency magnetic induction technology being described here. Sonar is plagued in shallow water with a difficult multipath propagation problem, noise on the signals caused by surf, and an inability to measure through intervening objects such as large rocks or abrupt dropoffs.

MI technology is decoupled from all of these problems. The one potential difficulty is distortion of the shape of the field due to magnetic anomalies or the finite thickness of the conducting water or even mixtures of fresh water in riverine areas. These distortions have been addressed by both the Navy and the program team and we believe they are well under control.

The principal benefit of this program will be demonstration and delivery of a working prototype of an MI navigation system from which can be derived many variations for a broad range of missions.

TRANSITIONS

Work under this program has led to a proposal being submitted to ONR's VSW / SZ MCM BAA 98-008 for incorporation of the technology onto a working AUV for demonstration purposes.

RELATED PROJECTS

There is significant effort underway in the areas of development of AUV platforms and mission packages which will require navigation services, MI technology being a prime candidate. Foster-Miller is involved with two DARPA SBIR programs. One program is investigating AUV platforms and the underwater instrumentation required for the general reconnaissance mission (Sea Snoop, DARPA SBIR 972-079). The other program is investigating integration of Synthetic Aperture Sonar with a bottom crawling AUV, and exploring whether motion compensation of the images is possible in this highly variable environment (SAS Snoop, DARPA SBIR 98-001).

REFERENCES

Foster-Miller Inc., 5 January 1998: STTR N97T005 Phase I Report
Foster-Miller Inc., 1 July 1998, STTR N97T005 Phase Final Report